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EVALUATE ERTS IMAGERY FOR MAPPING AND DETECTION OF CHANGES OF SNOWCOVER ON LAND AND ON GLACIERS

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16. Abstract

Snowlines on a small (6 km^2) drainage basin were accurately measured without use of digital processing, and snow patches as small as 150 m (maximum dimension) were correctly identified, proving that the resolution of ERTS is ample for snow mapping needs. The area of snowcover on 10 individual drainage basins in the North Cascades, Washington, has been determined at 12 different times; these data can be used for more accurate forecasts of streamflow. Progress has been made in distinguishing snow in trees using multispectral analysis. Motion of the surging Tweedsmuir Glacier was measured. Velocities ranged from 2 to 88 m per day; a zone of intense crevassing also appeared to spread up and down the glacier (at about 200 m per day upglacier). This tentative result may be of great importance to an understanding of surging glacier dynamics. ERTS images also show that the most recent debris flow (20-21 August 1973) from Mount Baker can be clearly discerned and mapped, in order to monitor this potential hazard.

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a. Title: Evaluate ERTS imagery for mapping and detection of changes of snowcover on land and on glaciers.

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c. Statement and expalanation of <u>any</u> problems that are impeding the progress of the investigation:

Missing data, because of cloud cover, non-acquisition, or non-transmittal, is still a serious problem.

d. Discussion of the accomplishments during the reporting period and those planned for the next reporting period:

Snow-covered area (in kilometres and percent) has been measured for 10 individual drainage basins in the North Cascades, Washington, all or some of which were measured with the Stanford ESIAC during 12 ERTS cycles. These data are now being analyzed in terms of a hydrologic model, and 4 additional basins and 1 additional cycle are being studied. Measurements have been started of snow-covered area and snowline altitude on images of the Mount Olympus region and an area in the southern Olympics to obtain a longer time-series of data.

A scanning densitometer has been used at many different magnifications and different resolution element sizes to study 70 mm ERTS transparencies showing snowcover in small drainage basins, in order to evaluate resolution, density contrasts at snow/no snow boundary, and accuracy of snow-covered area measurements in presence of shadows on snow and other materials of similar radiance (ice, firn, light-colored rock).

Experiments have been conducted on the ESIAC utilizing masks cut according to topographic contours. By cycling through a registered set of these masks on the display monitor, one can match the snowline to the best-fitting contour. This "variable contour overlay" promises to be another useful procedure for obtaining snow-covered area or snowline altitude.

High-altitude (U-2) and low-altitude aircraft data on snowlines are being analyzed as "ground truth" for the ERTS imagery. This is an extremely tedious process due to the complexity of the snowline, the problems with vegetation cover, and the relief distortion in photographs. Thus attempts will be made to devise statistical sampling and other techniques for streamlining the procedures.

Several other studies of snow-mapping accuracy are continuing, as are evaluations of the several snow identification strategies which can be used by eye or machine (i.e., simple density slicing, slicing on density gradients, subjective or quantitative identification of snow in shadows, multispectral and cluster analysis, etc.). Preliminary work has been done on all-digital processing. The problem of reading a combined signature of snow and trees has been approached by using a 2-dimensional color-space display (band 5 against band 6 or 7) in conjunction with the ESIAC. This permits the rapid selection and comparison of training sets and study of the fields they define on a color-space display.

Considerable additional work has been done on the measurement of ice movement and the movement of kinematic waves of thickness or crevassing on surging glaciers as seen on ERTS images, and on the monitoring of hazards such as glacio-volcanic debris flows.

Seven articles or talks on ERTS results were prepared. Also, an Operational Applications of Satellite Snowcover Observations program for the Northwest has been discussed with officials of NASA, EROS, BPA, Corps of Engineers, and NWS.

The next reporting period will be devoted to production of a final report.

e. Discussion of significant scientific results and their relationship to practical applications or operational problems including estimates of the cost benefits of any significant results.

Snowlines on a small (6 km^2) drainage basin were accurately identified on bulk ERTS images without use of digital processing and results checked with high-altitude and ground-based photography. The area and approximate shape of snow patches as small as 20,000 m^2 (maximum dimension: 150 m) could be correctly identified with a magnifying scanning densitometer using an 80 m circular resolution element. Thus the resolution of ERTS is more than ample for most snow-mapping needs.

The area of snowcover on 10 individual drainage basins in the North Cascades, Washington, has been determined for 29 July, 2 September, and 8 October 1972, and 30 May and 12 September 1973. In addition, snowcover on many of these basins has been measured on 14 November 1972 and 6 January, 12 February, 7 April, 25 April, 12 May, and 11 August 1973. A semi-automatic radiance threshold technique was employed. The result is a unique record of the changing water storage as snow in these important hydrologic units, the runoff of which is utilized for hydroelectric power, dilution of wastes and heat, salmon migration, and irrigation. These data will now allow a new type of hydrologic modelling to proceed which should permit more accurate forecasts of streamflow.

A new technique has been developed for measuring snow-covered area or snowline altitude semi-automatically. This variable contour overlay method involves superimposing an ERTS image on a monitor (ESIAC) with a registered series of contour masks which are rapidly cycled, thus permitting the snow-cover to be matched efficiently to the best fit contour of altitude. Repeatability of 60 m in altitude is readily obtained.

Although it is not yet possible to measure snowcover on an ERTS image by a fully automatic (digital processing) technique, progress has been made in distinguishing snow from other terrain materials in the absence of clouds. The band 7/band 5 radiance ratio is typically 0.5 for dry snow and less than 0.48 for wet snow; other typical terrain radiances show appreciably higher ratios. This technique may be of great value in identifying snow in deep shadows, a severe problem with other techniques. Using a color-space display connected to the ESIAC console, training sets could be immediately identified with their position on 2-dimensional color-space (usually band 5 against 6 or 7). As a result it was possible to define a color-space area which was directly between the clusters attributed to trees (evergreen) and snow. This presumably is a mixture of tree and snow radiances, indicating that some radiance was derived from snow between the nearly complete tree canopy. Using this technique, a mixed snow-tree area was mapped around the pure snow area of Mount Olympus. Thus if the canopy cover is not complete, it may be possible to map snow in forested terrains.

Motion of the Tweedsmuir Glacier was measured using ERTS images enlarged 1:50,000, using the facilities of the Geophysical Institute, University of Alaska. Changes detected included a shock wave moving up and down the glacier, the margin expanding, the moraine pattern deforming, and the marginal valley deepening. Velocities measured at 9 places in time and space ranged from 2 to 88 m per day; these clearly show the increase and then decrease in speed as the surge wave passed. These data have been confirmed by independent measurements made at the site by a Canadian glaciologist. In addition, these images suggest that a cone of intense crevassing (indicated by a darkening of the snow radiance) spread up-glacier at a very high rate of speed, about 200 m per day. This tentative result may be of great importance to an understanding of surging glacier dynamics, as it apparently shows the location where rapid movement began and how this rapid movement spread along the length of the glacier.

Tweedsmuir Glacier is now damming the large Alsek River, and the future release of this glacier dammed lake imperils settlements and a small industry at Dry Bay, Alaska.

The motion of the Yentna Glacier during the concluding phase of its surge was successfully measured by a "flicker" technique on the ESIAC using images of two dates. It appears that displacements as small as 100 to 2,000 m can be measured, which is very close to the resolution limit for a single ERTS image.

Mount Baker, Washington, has a large crater south of the summit and an area north of the summit which emit considerable geothermal heat in the form of fumaroles and hot ground. Temperatures here are being monitored using an ERTS Data Collection Platform. Also, debris flows are occasionally released from the crater due to water saturation at the base of a heavy snowpack lying on hydrothermally altered hot ground. These debris flows present a possible hazard to life and property, as they are discharged down the Boulder Glacier toward Baker Lake, the upper of two major hydroelectric power reservoirs which are situated above the populated Skagit River valley. Study of ERTS images shows that the most recent debris flow (20-21 August 1973) can be clearly discerned and mapped. Thus ERTS images provide another important tool for monitoring this potential hazard.

f. A listing of published articles, and/or papers, preprints, in-house reports, abstracts of talks, that were released during the reporting period:

Paper presented at Second Annual Symposium on Applications of Satellite and Airplane Remote Sensing of Natural Resources in the Pacific Northwest:

Krimmel, R.M., Use of ERTS images in glacier studies.

Papers prepared for EROS book on use of ERTS images:

Post, Austin, Meier, M. F., and Mayo, L. R., Measuring the motion of surging glaciers.

Krimmel, R. M., Post, Austin, and Meier, M. F., Monitoring surging glaciers.

Frank, David, Debris avalanches at Mount Baker volcano.

Krimmel, R. M., and Meier, M. F., Measuring snow-covered area to predict reservoir inflow.

Paper accepted for International Symposium on Remote Sensing in Glaciology, Cambridge, England:

Krimmel, R. M., and Meier, M. F., Glacier applications of ERTS images.

Colloquium "Remote Sensing of Snow and Ice" given at the University of Washington, 14 February, by M. F. Meier.

g. Recommendation concerning practical changes in operations, additional investigative effort, correlation of effort and/or results as related to a maximum utilization of the ERTS system.

None.

h. A listing by date of any changes in Standing Order Forms:

7 November 1972

1 May 1974

i. ERTS Image Descriptor forms:

In preparation.

j. Listing by date of any changed Data Request forms submitted to Goddard Space Flight Center/NDPF during the reporting period:

3 May 1974

k. Status of Data Collection Platforms:

N/A